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A Biocultural Perspective on Marianas Prehistory: Recent Trends in Bioarchaeological Research

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ABSTRACT Fifteen years ago, the biohistory of Micronesia was still a blank slate relative to other regions of the Pacific. Since 1980, however, the Mariana Islands, one of the largest island chains in Micronesia, have been the focus of intensive archaeological investigation and human remains have been ubiquitous components of the archaeological assemblages recovered from the islands of Guam, Rota, Tinian, and Saipan. These investigations have provided us with a wealth of new data that will contribute substantially to our understanding of population adaptation to island ecosystems in this part of the Pacific.

Much of the recent bioarchaeological research in the Marianas is the product of archaeological mitigation rather than directed research. Consequently, many of our research efforts have been articulated with the needs of cultural resource management (CRM) where research designs focus on several general problem areas: 1) subsistence adaptation with emphasis on the contribution of marine vs. terrestrial resources and the role of pelagic, or deep-ocean resources in the marine component of the diet; 2) regional (upland vs. coastal; interisland) and temporal variation in subsistence/settlement; and 3) geomorphologic variation in coastal sediments, particularly as influenced by storm events. Am J Phys Anthropol 104:271–290, 1997. © 1997 Wiley-Liss, Inc.

At the First Micronesian Archaeology Conference held on Guam in 1987 (Hunter-Anderson, 1990), a single session was devoted to the current state of research on the physical anthropology of Micronesia. Six papers were presented at this session. Four of them focused on the origins and affinities of Micronesians using craniometric and odontometric data (Brace, 1990; Howells, 1990; Pietrusewsky, 1990a; Turner, 1990). One paper focused on population dynamics and historical demography in the Mariana Islands (Underwood, 1990). And a final paper dealt with the epidemiological implications of morbidity and mortality observed in a small sample of prehistoric human remains recovered from the island of Rota in the Marianas (Hanson, 1990).

In his summary of this ground-breaking session, Pietrusewsky (1990b) highlighted four areas that needed to be addressed in Micronesian physical anthropology. He proposed that future research seek to: 1) fill the gap in our understanding of Micronesian population origins and affinities; 2) adopt a more rigorous demographic approach to

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evaluating population adaptation in Micronesia; 3) encourage more work by human biologists and geneticists to examine HLA blood antigens, mitochondrial DNA, and other biochemical attributes of both contemporary and prehistoric Micronesian populations, and 4) formulate research designs and testable models of biocultural interaction in island ecosystems which would articulate the theoretical/methodological objectives of the archaeologist with those of the physical anthropologist working with prehistoric human remains.

The purpose of this paper will be to 1) provide a broad overview of the current status of bioarchaeological research in the Marianas Islands—one of the largest island chains in Micronesia—and 2) present a framework for incorporating existing and new data into a regional synthesis of current knowledge focusing on the Marianas archipelago.

Due to major economic changes in recent years and the resulting pace of capital improvement in the Marianas, these islands have witnessed a burst of intensive archaeological activity. Human remains have been ubiquitous components of the archaeological assemblages recovered during mitigation. In the last 10 years, the remains of more than 1,500 individuals, most of these from sizable mortuary samples, have been recovered and examined by no fewer than a dozen anthropologists.

Given the number of investigators currently involved in research in the Marianas and the ephemeral nature of the collections of human skeletal materials we work with, one of our goals is to develop an extensive collaborative research network that would enable multiple investigators to participate in the study of a given mortuary sample prior to reburial. With the adoption of more formal cooperative research agreements and the sharing of data resources between different investigators, the Mariana Islands will serve as an ideal testbed for modeling human adaptive response in tropical and subtropical island ecosystems.

THE MARIANA ISLANDS

The Marianas archipelago consists of a chain of 15 islands stretching north-south between 13 and 20°N latitude and distributed in two distinct arcs (Fig. 1). The northern arc consists of steeply sloping islands of recent volcanic origin while those of the southern arc are predominantly large raised platforms of coralline limestone on much older volcanic bases. The southern islands are generally larger in area, ranging in size from 7 to 540 km^2, and have lower elevations and more diverse coastal margins than the northern islands.

Evaluating changes in coastal landforms brought about by sea level change, tectonic uplift, and sedimentary processes over the last several millennia is critical to interpreting the archaeological record in the Marianas (Hunter-Anderson and Butler, 1995). Most of the earliest settlements in the Marianas were located very near the shorelines where archaeological deposits are particularly susceptible to changes in sea level and storms. Although later occupations included inland sites, the bulk of human settlement in the Marianas occupied coastal margins. Consequently much of our understanding of human biocultural adaptation in the Marianas is closely tied to geomorphologic change in coastal landforms. It is within the context of these dynamic coastal margins that the distribution, recovery, and interpretation of human mortuary remains are best understood.

Butler (1995) has presented a working model of land and sea level relationships in the Marianas. The geological history of the southern islands can be characterized generally by substantial tectonic uplift in the last 3,000 years. It has been estimated that land and sea level relationships reached an equilibrium between 4000 and 5000 BP. Around 3000 BP, the land began to rise faster than sea level until, sometime within the last 1,000 years, another equilibrium was reached.

The large southern islands are complex geological structures, and it appears that the timing of the Holocene uplift and the extent of shoreline response to these changes may vary substantially among the islands. In many cases, modification of shorelines follows a pattern consistent with rising sea level such as the drowning of drainages or erosional features to form bays, inlets, and lagoons. In other situations, local conditions

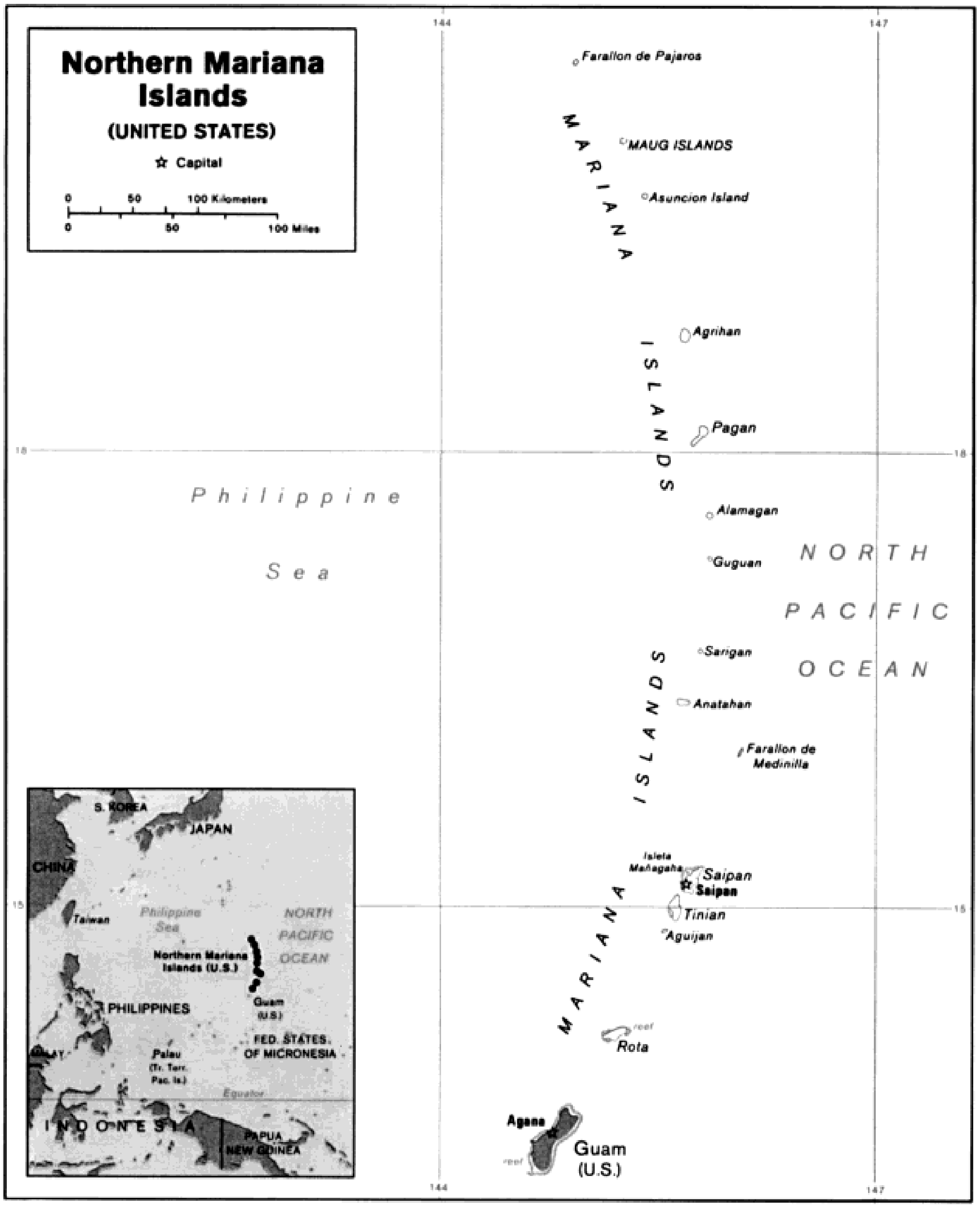

Fig. 1. The Mariana Islands.

may actually constrain the potential effects of a period of dynamic change in land/sea level relationships. Several of the beaches on Guam, Rota, and Saipan, for instance, appear to have stabilized in their present position nearly 2,000 years ago. In contrast, other regions underwent considerable modification, such as the west coast of Saipan within the barrier reef (Butler and DeFant, 1989). Along this coast, beaches in some areas receded while formation was occurring in others. New barrier spits were formed, moved rapidly seaward, and were accompanied by the filling of former lagoon

and estuary areas and by their slow transformation into marsh and swamp. Once stabilized, these new strand areas were quickly occupied.

The gradual sedimentary infilling of a series of coastal lagoons is one of the more significant changes which has taken place in the coastal environments in the Marianas over the last 3,000 years. The infilling of these marine ecotones and the associated changes in flora and fauna are characterized by a gradual increase and then reduction in biological diversity. In the Marianas, former lagoon environments are now reed marshes. Island inhabitants had access to these biologically diverse lagoon environments until about 2,000 years ago, when they began to fill with sediment.

The paleoclimatological record of the Marianas is somewhat less well known than its geomorphologic history. Today the climate is marine tropical with a pronounced summer monsoon which is frequently punctuated by tropical cyclones. Tropical storms produce a significant proportion of the annual rainfall, which ranges from 70 in in the northernmost islands to a maximum of 100 in in the southern islands. The El Niño/Southern Oscillation phenomena are also a prominent part of the climate in this area and result in drought cycles of between 2 and 7 years (van der Brug, 1986).

Natural plant communities in the Marianas consist of drought- and typhoon-resistant species and exist alongside cultigens from the Indo-Malayan biotic province which were introduced by prehistoric peoples during the initial settlement of the islands. Major domesticates include breadfruit, taro, several species of yams, bananas, coconuts, and betel nut. Although rice was grown in historic times, there is some evidence to suggest that it was an important ritual food (Driver, 1988) and perhaps used at feasts (Hunter-Anderson, et al., 1995) during prehistoric times.

The distribution of marine resources in the Marianas is generally consistent with the observed differences in geology between the northern and southern groups of islands. In the northern islands, numerous species of reef and bottomfish live in coastal waters along with pelagic species normally found far off-shore in the southern islands. The presence of fringing reefs and lagoons in the southern islands is more conducive to reef species which thrive in lower energy habitats. The relative lack of lagoons and reef environments in the Marianas compared to other regions of Micronesia fostered a greater emphasis on deep-sea fishing. However, the temporal and spatial unevenness in the distribution of pelagic resources and other constraints on successful deep-ocean catches made deep-sea fishing a less reliable source of marine food than reef fishing.

POPULATION HISTORY

At the time of initial contact with Europeans in 1521, the Mariana Islands were inhabited by a single people who were to become known as the Chamorro. Critical evaluation of early Spanish colonial accounts and later colonial census data (Underwood, 1973; Hezel, 1982) suggests a maximum precontact population ranging in size between 30,000 and 40,000 (Hezel, 1982; Hezel and Driver, 1988). This yields an average population density for the southern Marianas between 30 and 40 persons per km^2, which is low compared to other island groups in Micronesia. The peak precontact population density in Yap, for instance, was approximately 335 persons per km^2 (Hunter-Anderson, 1983). Butler's (1995) recent archaeological survey of Aguiguan, the smallest of the southern islands at 7 km^2, however, suggests a maximum late prehistoric population density of approximately 70 persons per km^2—an indication that population density may have varied considerably between islands in the Marianas.

Contact with Europeans was sporadic after 1521 and consisted of occasional dealings with ships on their way to the Philippines, castaways, and several deserters. It was not until 1668, when the Jesuits, led by Fr. Diego Luis de Sanvitores, founded a permanent mission on Guam, that *reduccion* and Spanish colonization began in earnest. The Jesuit mission enjoyed considerable success during its first 2 years, but continued attempts at conversion only led to increasing hostility and violence which culminated in the slaying of Sanvitores in 1672. Because of continued unrest the Spanish civil authori-

ties took control of the colony in 1676. The period from 1670 to 1695 is characterized by sporadic outbreaks of violence. Major uprisings occurred in 1670 and 1684 and threatened to undermine Spanish control of the islands. In 1680, several military campaigns were launched to systematically destroy hostile villages and relocate populations to areas more easily controlled by the authorities. The Chamorro responded in 1684 by organizing a large scale rebellion with the specific intent of crushing Spanish authority. Following the uprising of 1684, the Spanish left the northern islands in peace for 10 years and focused their military efforts on Guam. By 1700 Spanish expeditions had forced the relocation of nearly all the remaining inhabitants of the islands north of Rota to Guam. Except for a few refugees and a single settlement on Saipan, the Mariana Islands north of Rota were depopulated.

Like many indigenous populations throughout the New World who came into contact with Europeans (Larsen, 1994), the Chamorro experienced a catastrophic decline in population (Fig. 2). In less than 100 years, the indigenous population dropped from an estimated maximum size of 40,000 in the late 17th century to approximately 1,500 individuals (Underwood, 1973)—a 96% reduction in population. Only a small part of this reduction may be attributed to the repressive colonial administration and Spanish military campaigns. Epidemics of diseases introduced by Europeans were largely responsible for the catastrophic population declines (Hezel, 1982; Hezel and Driver, 1988). Highly contagious viral diseases such as smallpox and influenza, combined with the densely settled coastal villages on these islands, played a major role in contributing to the demographic collapse of the indigenous Chamorro.

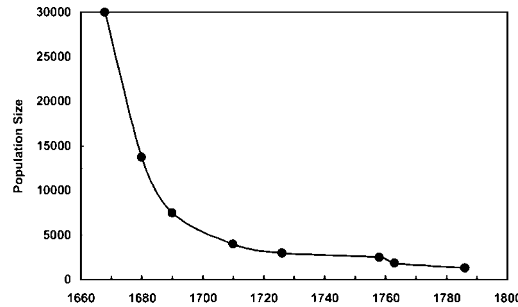

Fig. 2. Population decline in the Marianas, 1668–1786.

TABLE 1. Chronological sequence for the Mariana Islands[1]

Period	Date range (calendar years)
Early Pre-Latte	1800 BC–500 BC
Intermediate Pre-Latte	500 BC–AD 1
Transitional Pre-Latte	AD 1–AD 1000
Latte	AD 1000–AD 1521
Early Historic	AD 1521–AD 1700

[1] Based on Moore (1988).

ARCHAEOLOGICAL BACKGROUND

Modern archaeological work in the Marianas was initiated by Alexander Spoehr (1957), whose definition of the Latte and Pre-Latte periods is still the terminological basis of the local chronological sequence. The temporal framework currently used in the Marianas (Table 1) is based largely on Moore's (1988) revision of Spoehr's pre-^{14}C scheme, using dated ceramic sequences. The defining characteristics of these periods are based on the ceramics and the appearance, in the Latte Period, of a distinctive megalithic building style.

The earliest reliably dated archaeological deposits in the Marianas date to approximately 3,500 years ago (Butler, 1994). These early deposits have been found only in sandy coastal settings beneath later prehistoric occupations (Hunter-Anderson and Butler, 1995). Many of the early deposits have been subject to extensive reworking or redeposition by major storm events and are not preserved intact. The discovery of intact early deposits is rare and consequently little is known about the early occupation of the islands. It is known that the first settlers were peoples from insular Southeast Asia who brought with them a refined ceramic technology and presumably most of the cultigens important to Oceanic societies (Butler, 1994). The ceramics from the early period are characterized by well-made, calcareous, sand-tempered red wares made from locally procured raw materials. The Intermediate and Transitional Pre-Latte periods are subdivisions that primarily reflect gradual

Fig. 3. A latte structure on Rota. Note the two standing limestone uprights in the foreground with fallen capstone partially obscured by grass on left. Also note the last standing upright in the row in the background on left. This latte structure originally consisted of four pairs of uprights and capstones. View is down the length of the two parallel rows of capstones. Meter stick is graduated in 5 cm intervals.

changes in ceramic forms and the emergence of various local nonceramic artifact forms.

The late prehistoric Latte Period is characterized by the emergence of a distinctive cultural pattern and is the only period for which archaeologists can assemble a detailed picture of settlement distribution, village organization, and mortuary patterns. The period is specifically distinguished by the appearance of latte stone architecture. A latte structure consists of limestone or basalt pillars topped by hemispherical capstones arranged in opposing pairs to form two parallel rows per structure (Fig. 3). This parallel arrangement of columns and capstones presumably provided support for a wooden superstructure. The number of opposing pairs of stone ranged from two to 12, but four to five pairs were more common. The height and weight of individual columns and capstones ranged from waist height and a few hundred kilograms to stones over 5 m high and weighing several metric tons.

There is still considerable disagreement among archaeologists about the significance of these structures (Butler, 1992; Graves, 1986, 1991; Hunter-Anderson, 1989, 1995). Hunter-Anderson (1989, 1995) argues that latte may not have always served as residential structures and instead acted as territorial markers for claiming land and resources in a particular area. According to Butler (1992), however, the weight of a wooden superstructure was critical to holding the unstable capstones in place, thus maintaining the architectural integrity of the latte structure.

If latte served primarily as residential units, were all dwellings supported by these stone structures or was their use limited to a privileged few? Most of the available archaeologic and ethnohistoric data indicate that at the very least all of the important principal houses were raised on them. Graves (1986, 1991) goes further to suggest that all latte-supported structures were residences of higher-ranking members of lineages or clans

and that the descent group was represented by more than one latte structure. The physical size of the structure, particularly its height, is the attribute considered most symbolic of authority and rank (Graves, 1991). The vast majority of residential latte structures in the Marianas are 1.0 to 1.5 m in height and are grouped in clusters near much larger latte structures, which in a few cases exceed 3 m in height.

Latte structures are particularly important with respect to bioarchaeological research since these structures are the primary locus of late prehistoric mortuary activity in the Marianas (Graves, 1986, 1991; Hanson and Gordon, 1989). Mortuary activity was only one of several components of daily occupational use centered around these residential units. There is some evidence to indicate that special use areas were also set aside to be used exclusively for mortuary treatment and disposal (Hanson and Gordon, 1989). Recent excavations on Guam, for instance, have revealed that separate disposal areas for cremation and primary inhumation were utilized by the prehistoric Chamorro (M. Ryan, personal communication). In addition, LauLau Rockshelter, excavated by Spoehr in the late 1940s, is one of the few example in the Marianas of a separate disposal area that was the focus of mortuary activity during both the Pre-Latte and Latte periods (Spoehr, 1957).

Although Graves (1986, 1991) has suggested that latte burial was restricted primarily to adults, investigations on Rota (Hanson, 1988) and more recently on Guam (Ryan, 1995) clearly demonstrate that subadults were a significant component of the late prehistoric mortuary domain. Graves' analyses of mortuary activity were based largely on skeletal material recovered by Hans Hornbostel in the 1920s, which is currently curated at the Bishop Museum. Age biases in the Hornbostel mortuary sample have been duly noted by Underwood (1995) and by Hanson (1995), who suggested that the Hornbostel sample is most likely a product of selective recovery in which only the best preserved materials were retained and the less well-preserved materials were either purposely excluded from recovery or not recognized as human. This is further supported by a more recent detailed study of Hornbostel's notes and the collection itself (Ikehara-Quebral, personal communication).

CURRENT BIOARCHAEOLOGICAL RESEARCH

The Airport Road Project on the island of Rota in 1984 was the first effort in the Marianas to develop a research design which sought to integrate the theoretical/methodological objectives of the archaeologist responsible for the project with those of a mortuary archaeologist/human osteologist (Butler, 1988). With the rapid pace of economic development in the Marianas, the bulk of the ongoing archaeological research in Micronesia is taking place on these islands and in the last few years, several large mitigation projects on the islands of Guam and Saipan have focused predominantly on mortuary samples.

Since 1980, the remains of more than 1,500 individuals have been recovered, analyzed and reported on by as many as 12 different investigators (Table 2). Despite the wealth of new data, the results of many of these studies remain unpublished and a regional synthesis of the accumulated data is still forthcoming. The papers presented in this issue represent a first step in identifying some of the general trends in the Marianas bioarchaeological data. An important caveat regarding these studies is that the vast majority of mortuary samples recovered to date are temporally limited to the late prehistoric/early historic periods of occupation. Therefore much of our understanding of prehistoric human biology in the Marianas is restricted primarily to the Latte Period.

Bone preservation and taphonomic considerations

One of the primary constraints in the recovery and analysis of human skeletal remains in the Marianas is bone preservation. The generally poor bone preservation observed in skeletal materials recovered throughout the Marianas underscores the need for close working relationships between archaeologists and osteologists (Hanson, 1995). The recent work of Hunter-Anderson and her colleagues at Mannengon

TABLE 2. Human osteology in the Marianas since 1980

Island	Project/site	MNI*	Reference
Guam	San Vitores Rd, Tumon	63	Pietrusewsky, 1986a
	East Agana Road	1	Pietrusewsky, 1988a
	NAVFAC, Ritidian	3	Heathcote, 1990
	ABC Condo	1	Heathcote, 1991
	Waterpark Site	3	Heathcote, 1993
	Gongna/Gun Beach	164	Anderson, 1992
	Gongna/Gun Beach	17	Stodder, 1992a
	Camp Watkins	29	Stodder, 1992b
	Mangilao Golf Course	41	Stodder, 1993
	Apurguan	152	Pietrusewsky et al., 1991
	Leo Palace Site	27	Douglas and Ikehara, 1992
	San Antonio Burial Trench	25	Hanson, 1991
	Hyatt Hotel Site	484	Ryan et al., in preparation
	Inarajan Garden House	5	Dilli et al., 1994
	Royal Palm Resort	3	Dilli et al., 1993
	AT&T Tumon Bay	11	Grant et al., 1992
	Manenggon Hills	8	Heathcote, 1994
	Manenggon Hills	38	Eakin, 1994
Rota	Mochong	1	Webb, 1988
	SongSong Village	12	Pietrusewsky, 1988b
	Airport Road	27	Hanson, 1988
	Alaguan	5	Craib, 1990
Tinian	Latte House Site	6	Pietrusewsky and Batista, 1980
	Unai Chulu Site	14	Pietrusewsky, 1986b
Saipan	Marianas High School	6	Pietrusewsky and Batista, 1980
	Grotto Site	2	Pietrusewsky and Batista, 1980
	San Antonio	33	Pietrusewsky and Batista, 1980
	Hafa'Adai Beach Hotel	20	Pietrusewsky, 1986b
	Tanapag	7	Pietrusewsky, 1986b
	Oleai	34	Pietrusewsky and Douglas, 1989
	Duty Free, Garapan	9	Hanson, 1989
	San Antonio	25	Tayles and Roy, 1989
	Duty Free Expansion	25	Henry et al., 1993
	Oleai Mobil	6	Hanson, in preparation, a
	Hafa'Adai Beach Hotel	62	Hanson, in preparation, b
	Microl Corp. Repair Shop	1	Leap et al., 1991

*MNI, minimum number of individuals.

Hills (Hunter-Anderson et al., 1995) in the interior of Guam typifies the worst-case scenario in which the poor preservation required that osteological analyses be performed in the field. Even in coastal beach sands where good drainage might herald the prospect of well-preserved bone, we are more likely than not faced with fragmentary remains.

There are clearly many factors which can influence bone preservation in both coastal and inland deposits of these islands. These range from soil factors such as the coralline limestone based soil matrices to mechanical factors such as wave action from storm events (e.g. Hanson, 1995). Given the numerous conditions which can affect the preservation of human remains in the Marianas, a more explicit taphonomic approach to the recovery and analysis human remains is warranted such as that advocated by Nawrocki (1995) in his recent analysis of the taphonomic processes affecting historic cemeteries. This would include identification of the individual, environmental, and cultural processes which affect the survival, recovery, and analysis of human remains. By adopting an approach which seeks to identify some of the mechanisms responsible for either enhancing human bone preservation or accelerating its deterioration we not only help to minimize the impact of poor preservation on biological and mortuary data recovery in the Marianas but may also assist with the more general problem of understanding geomorphologic change in coastal and inland environments (Hanson, 1995).

Prehistoric diet

Contemporary Pacific island diets are generally characterized as predominantly vegetarian, consisting primarily of root and tree

starches with fish serving as a supplement (Malcolm, 1955; Marshall, 1985; Pollock, 1986a, 1992). Early ethnohistoric sources for the Marianas are rarely specific and frequently contradictory regarding the relative contributions of terrestrial and marine resources to the diet. It was believed by many Europeans that the Chamorro diet was deficient in protein which prompted the Spanish introduction of the pig as a protein resource (Pollock, 1986b), but probably more for the dietary benefit of the colonists than the indigenous population. Father Sanvitores noted that the primary food is roots "which serve as a preliminary, a main course and dessert without meat, bread or wine" (Pollock, 1986b:129). However, Sanvitores is also credited with writing in 1670 that "the ordinary food of this people is fish, which is highly prized" (Barrett, 1975:19).

Stable isotope data for late prehistoric remains from the Marianas provide support for the notion that marine resources supplemented the predominantly terrestrial diet of the prehistoric Chamorro (Hanson, 1989, 1991; Ambrose, 1993; Ambrose et al. 1994, 1997, Quinn, 1990; McGovern-Wilson and Quinn, 1996). Hanson (1989, 1991) first reported stable isotope data for two small samples from coastal Guam and Saipan. The dietary $\delta^{13}C$ and $\delta^{15}N$ of these samples indicated that marine resources made up less than 30% of the late prehistoric diet and that the marine component of the diet consisted of lagoon or reef species. McGovern-Wilson and Quinn (1996) analyzed stable carbon and nitrogen ratios in a sample of 10 individuals representing the earlier Transitional Pre-Latte Period (AD 1–AD 1000) from Afetna, Saipan. Their findings suggest a similar dependence on terrestrial resources with marine foods making up approximately 35% of the diet. A much higher $\delta^{15}N$ for the Afetna sample than for the Duty Free sample from Saipan led McGovern-Wilson and Quinn to conclude that the marine component of the diet in the Afetna sample consisted of a larger percentage of pelagic resources.

Ambrose (1993) and Ambrose et al. (1994, 1997) included not only larger sample sizes from Guam, Rota, and Saipan, but Ambrose has also performed a food web analysis of marine and terrestrial food resources. Furthermore, Ambrose has determined the carbon isotope ratios for apatite carbonate in addition to collagen in these samples. Apatite carbon ratios provide us with a more accurate picture of the whole diet carbon isotope ratio. Since the bone collagen carbon isotope ratio alone discriminates in favor of protein, it generally overestimates the marine food component of the diet and underestimates low-protein food resources. Thus, protein-rich C_3 food resources could conceivably mask the isotopic signature produced by low protein C_4 food resources when using carbon isotopic ratios based on collagen alone.

Ambrose's data offer additional support for the general model of late prehistoric diet based largely on terrestrial resources supplemented by marine foods with a primary focus on lagoon and reef species rather than deep ocean species. Ambrose, however, has noted two very distinctive inter-island variations in diet. First, the relative proportions of pelagic resources in the marine component of the diet was much greater for the late prehistoric inhabitants of Rota than for the coastal inhabitants of either Saipan or Guam. This is probably due to the lack of well-developed reef environments on the island of Rota (Eldredge and Randall, 1980). The late prehistoric fish bone assemblages from archaeological deposits along the northern coast of Rota also confirm a substantial emphasis on pelagic species (Davidson and Leach, 1988).

Second, when the carbon isotope values for apatite were analyzed within the context of nitrogen and carbon isotope ratios for collagen, Ambrose was able to identify a previously unrecognized C_4 component of the Marianas diet (Ambrose, 1997). He suggests that this component of the diet may be either seaweed or sugar cane. However, there are still no archaeobotanic, archaeologic, or ethnohistoric data to support this.

A comparison of mean $\delta^{13}C$ and $\delta^{15}N$ bone collagen values for the Marianas and selected island and coastal populations with different fishing economies prior to the introduction of maize into the diet is presented in Figure 4. These include the Bahamas (Keegan and DeNiro, 1988), southern California coast (Walker and DeNiro, 1986), and southeastern U.S. Atlantic coast (Larsen et al., 1992). The bone collagen isotopic signa-

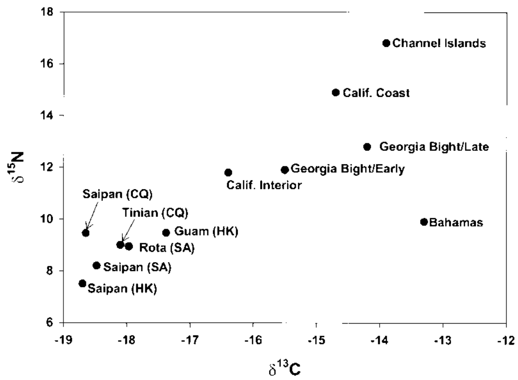

Fig. 4. Mean $\delta^{13}C$ and $\delta^{15}N$ collagen values for the Marianas and selected island and coastal mainland populations (SA = Stan Ambrose Lab; HK = Harold Krueger Lab; CQ = Carol Quinn Lab).

tures for the Marianas form a distinctive cluster. Although this is due in part to differences in the isotopic composition of the respective food webs, dietary differences probably account for some of the variation. Compared to other coastal mainland or island populations, the late prehistoric inhabitants of the Marianas probably put a proportionately greater dietary emphasis on C_3 terrestrial resources and had a greater dependence on reef resources than on deep ocean resources in the marine component of the diet.

Dental health

A dietary emphasis on mostly starchy root cultigens and tree species generally predisposes a population towards a high prevalence of caries (Walker and Erlandson, 1986). However, the prevalence of adult caries in late prehistoric coastal village populations of the Marianas is low (Table 3; Fig. 5) and significant attrition, periodontal disease, and antemortem tooth loss in the mortuary samples which have been studied usually do not occur until well after the age of 35 years (Hanson, 1995).

Hanson (1989, 1995) has reviewed many of the factors which may be responsible for the apparent good dental health of the prehistoric Chamorro. Perhaps the most significant factor contributing to low caries frequencies in the Marianas is betel-chewing.

Incidental staining of the teeth through use of the areca nut *(Areca catechu)*, betel leaf *(Piper betle)*, and slaked lime ($CaCO_3$) is ubiquitous in the adult component of our mortuary samples as indicated by the light to dark brown staining of the enamel involving the incisor through molar regions in the upper and lower dentitions. In most of the samples examined to date, betel-staining of the enamel rarely occurs prior to the age of 16 years and after the age of 23, betel-staining is noted to some degree in the permanent teeth of approximately 92% of all adult dentitions examined.

There is a substantial epidemiological literature demonstrating a link between betel-chewing and cariostasis (Chandra and Desai, 1970; Howden, 1982; Möller et al., 1977; Nigam and Srivastava, 1990; Schamschula et al., 1977; Senewiratne and Uragoda, 1973). However, few studies have actually explored the mechanisms which may prevent caries in betel-chewers. Chewing betel-nut performs several roles in cariostasis. First, like other abrasives and fibrous masticatories, the rough fibers of the betel quid cleanse tooth surfaces and accelerate the abrasion of occlusal enamel which removes potential sites of cariogenic activity. Second, regular use of betel-nut reduces appetite, thus diminishing the cariogenic potential of the diet. Third, betel-chewing increases saliva flow and the production of salivary proteins responsible for inhibiting bacterial activity (Iwamoto et al., 1991). Fourth, the high pH of the slaked lime increases the alkalinity of the oral environment to help neutralize the formation of acids responsible for dissolution of enamel (Schamschula et al., 1978). Finally, it has been suggested that the calcified red-to-black film, which is morphologically identical to calculus and forms primarily on smooth surfaces of teeth, acts a physical barrier against diffusion of cariogenic agents into the enamel surface (Reichart et al., 1984).

One experimental study demonstrated that betel-stained enamel is more resistant to acid etching than non-stained enamel (Howden, 1984). Preliminary results from an EM study of enamel morphology in betel-stained teeth from Guam (Stern and Hanson, 1995) show an initial seepage phenomenon from prism sheaths which results in the eventual eradication of a distinct prism

TABLE 3. Frequency of caries in the Mariana Islands and representative island groups

Island/island group	NTO*	NTC**	%	Sources
Guam	4143	108	2.6	Hanson, 1991; Stodder, 1992a,b, 1993; Pietrusewsky et al., 1991; Douglas and Ikehara, 1992; Anderson, personal communication
Rota	414	12	2.9	Hanson, 1988; Pietrusewsky, 1988b
Saipan	902	52	5.8	Pietrusewsky, 1986b; Hanson, 1989; Tayles and Roy, 1989; Pietrusewsky and Douglas, 1989
Hawaiian Islands	8292	1160	14.0	Pietrusewsky and Douglas, 1994
Santa Rosa, Early	1718	229	13.3	Walker and Erlandson, 1986
Santa Rosa, Late	934	59	6.3	Walker and Erlandson, 1986

*NTO, number of teeth observed.
**NTC, number of teeth with one or more caries.

morphology (Fig. 6). Several studies have been initiated to elucidate the possible role of betel staining in cariostasis (Stern and Hanson, 1995).

In contrast to permanent dentitions, caries are much more prevalent in deciduous teeth. In a sample from Guam, Stodder (1993) reported a mean of 2.67 carious deciduous teeth per individual and a mean of 0.58 carious permanent teeth in individuals 16 years and older. In a sample from the north coast of Rota, a mean of 4.2 carious deciduous teeth per individual and a mean of 0.65 carious permanent teeth in individuals 23 years and older is reported (Hanson, 1988). In the Rota sample, one or more carious lesions occurred in 33% of all (n = 93) fully erupted deciduous teeth examined (Fig. 7). In addition, 73% of the carious deciduous teeth in the Rota sample displayed linear, smooth surface lesions characteristic of circular caries (Cook and Buikstra, 1979) frequently found in association with enamel hypoplasias. Individuals who experienced circular caries in the Rota sample did not survive beyond the age of 6 years.

The infant and early childhood morbidity (caries, dental defects, periostitis, and po-

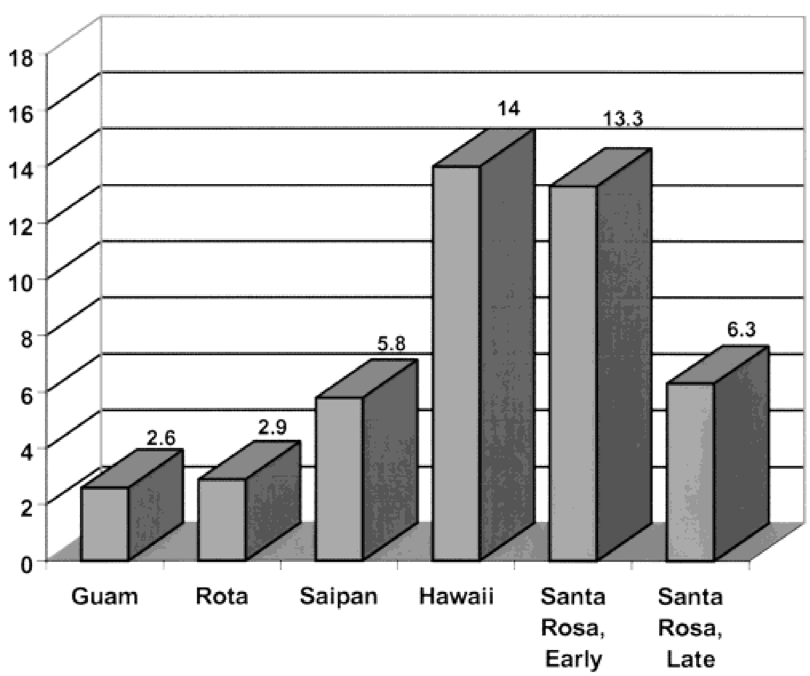

Fig. 5. Representative caries frequencies in the Mariana Islands compared with other island populations.

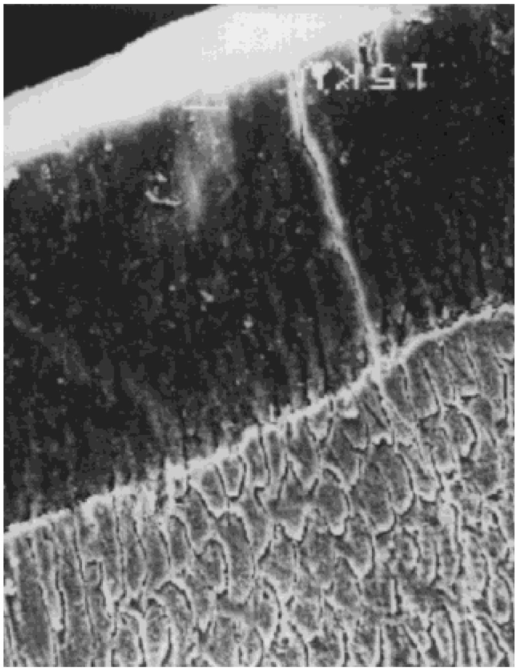

Fig. 6. Penetration of betel-stain into enamel surface in maxillary canine. Depth of stain penentration in this view is approximately 40 µ. Note the altered prism morphology in stained region (photo courtesy of D. Stern).

rotic hyperostosis) and mortality observed by Hanson (1988) in his work with materials from Rota clearly suggests some level of individual systemic stress experienced during pregnancy and early childhood development. Hanson (1990) suggested that early weaning may have played a role in the morbidity and mortality experience of the subadults from Rota. Stodder's (1997) recent work with enamel hypoplasia in samples from the island of Guam suggests the possibility of a benchmark weaning age in the Marianas as early as 1.5 years. Alternatively, the observed pattern of errors in the developing enamel may be related to relatively early and chronic exposure to infectious disease organisms.

Infectious disease

Non-specific periosteal reactions and skeletal lesions characteristic of treponemal infection, presumably yaws caused by *Treponema pertenue*, are the two most frequently observed infectious conditions in prehistoric human remains from the Marianas. The antiquity of yaws in the Marianas was first demonstrated in remains recovered from the island of Tinian in the landmark study by Stewart and Spoehr (1952). Since then, yaws has been identified in skeletal assemblages throughout the Marianas including Guam (Anderson, n.d., Douglas et al., 1997; Pietrusewsky et al., 1997; Rothschild and Heathcote, 1993; Stodder, 1992a, 1993; Stodder et al., 1992; Trembly 1996), Rota (Hanson, 1988; Pietrusewsky, 1989b) and Saipan (Hanson, in preparation, a; Tayles and Milburn, 1995; Pietrusewsky et al., 1997).

Because of the poor recovery and preservation in many of these assemblages, it has been difficult to obtain meaningful data on the frequency and prevalence of yaws. Nevertheless, several large, recently recovered mortuary samples from the Tumon and Agaña Bays on Guam have revealed lesion patterning and frequency distributions which would suggest a hyperendemic focus for yaws on Guam along the heavily populated northwestern coast of the island. In a study of 202 individual skeletons from several Latte Period sites on Guam in which at least one tibia, one fibula, and one other long bone or the cranium were present, Stodder et al. (1992) reported that 21% of the sample displayed lesions characteristic of secondary or tertiary yaws. This included 9% of the subadults (n = 68) and 26% of the adults (n = 134). Similarly, Rothschild and Heathcote (1993) reported a frequency of yaws-like periostitis in 19% of a sample (n = 213) from Gognga-Gun Beach. Six percent of subadult skeletons aged 6–10 displayed evidence of treponemal infection, while nearly 20% of individuals aged 11–40 displayed these lesions. Finally, in their study of the Latte Period Apurguan remains from the adjacent Agaña Bay on Guam, Douglas et al. (1997) reported that 7% of their sample (n = 152) displayed yaws-like lesions including 2% of the subadults (n = 51) and 9% of the adults (n = 101).

Cortical bone dynamics

Cortical bone cross-sectional geometry and histomorphometry is used to assess the gen-

Fig. 7. Caries in fully erupted left maxillary deciduous teeth from a Latte Period deposit on Rota.

eral health status of a past populations (Larsen and Ruff, 1994; Ruff, 1992). Although the long bones are generally used for such studies, complete long bones from archaeological deposits in the Marianas are rare. Instead, we are currently in the process of evaluating cortical bone geometry and histomorphometry of the second metacarpals and metatarsals of several mortuary samples from the Marianas. Metapodials were selected for analysis for several reasons: 1) their relatively small size facilitates study of morphometric properties, 2) they have different functions with respect to weight-bearing and functional loading, 3) they are frequently found intact in archaeological deposits in the Marianas, and 4) a considerable amount of comparative morphometric data exists for the second metacarpal including one study for the contemporary Chamorro (Plato et al., 1982, 1984; Garruto et al., 1989; Greulich, 1951).

A pilot project (Hanson, 1988, 1989) to determine the effectiveness of using these bones for morphometric studies demonstrated generalized osteoporosis in the appendicular skeleton, i.e., metatarsals and metacarpals from the same individual both displayed endosteal porosity (Fig. 8). Preliminary data on cross-sectional areas normalized for bone length in the second metacarpal support the general human aging pattern of subperiosteal expansion and endosteal resorption. In addition, the data from the sample to date ($n = 15$), which consists predominantly of females from Rota, suggest that the age of onset of significant bone loss is about 35–40 years, which is comparable to the age of onset for contemporary Chamorro women (Plato et al., 1982). On Saipan, the onset of significant bone loss in females may have been delayed by as much as a decade. When comparing old adult (>50 years) males and females in the combined sample, it was found that percent cortical area in males exceeded that of females by 12%. This sex difference was related to a total subperiosteal area which was 30% greater in males than in females (Hanson, 1989). There was no difference in medullary areas in this age group.

Skeletal responses to biomechanical stress

The prehistoric Chamorro exhibit a number of skeletal features indicative of significant levels of physical activity and habitual motion. Until recently however, our samples have been limited by small size or inadequate preservation to provide us with good quantitative information on the skeletal and interisland variation in these conditions. Two conditions have been observed to occur with regular frequency in mortuary samples from the Marianas—L5 spondylolysis (Arriaza, 1997) and occipital/peri-asterionic tubercles of the basi-occipital region of the cranium (Heathcote et al., 1995).

In a recent study of 176 Latte Period skeletons from the Tumon Bay region of Guam, only 38 individuals had complete vertebral columns, and 21% of these displayed evidence of complete, bilateral L5 spondylolysis at pars interarticularis (Haun and Arriaza, 1992; Arriaza, 1997). In con-

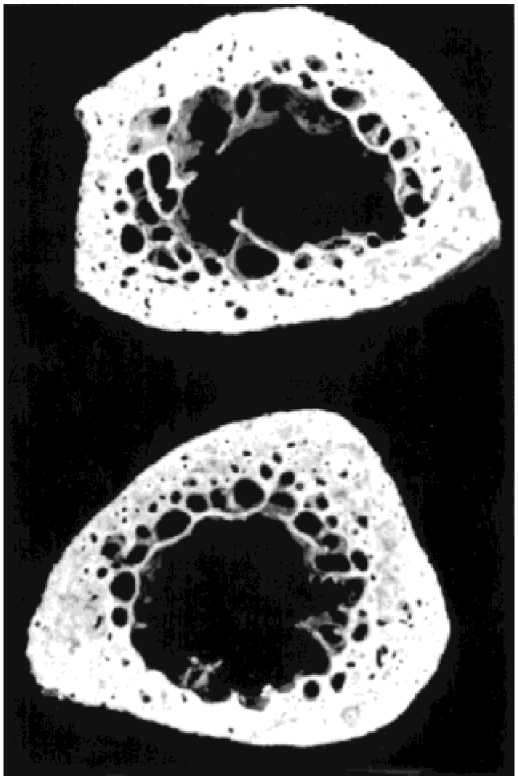

Fig. 8. Endosteal porosity in midshafts of left second metacarpal (top) and left second metatarsal from Latte Period Rotanese female aged 45–50 years.

Fig. 9. Cast of occipital bone from Early Historic Period female aged 40–44 years recovered from a deposit on Saipan. Note the large, bilaterally symmetric, pedunculated tubercles along the nuchal crest and the enlarged retromastoid processes.

trast, Stodder (1993) and Stodder et al. (1992) reported much smaller frequencies of 4% (1/26) and 5% (5/76) in the Mangilao Golf Course and Camp Watkins samples from Guam. According to Pietrusewsky et al. (1997), spondylolysis appears to be largely restricted to some of the larger coastal village samples from Guam with frequencies (based on minimum number of individuals [MNI] rather than complete spines) ranging from 6 to 20%. However, this may be a function of much smaller sample sizes recovered outside of Guam. Nevertheless, Hanson (1995) reported a case of L5 spondylolysis in a well-preserved female skeleton from Saipan dated to the Early Historic Period—an individual who may have been an immigrant from Guam based on an isotopic signature which was similar to Guamanian signatures and well outside the cluster of signatures available for Saipan samples (Ambrose, personal communication).

One of the more distinctive cranial features observed in prehistoric skeletal remains from the Marianas is the appearance of large tubercles in the basi-occiput. Heathcote et al. (1995) have thoroughly documented the variation and geographic distribution of these cranial structures. Figure 9 exhibits an example of the extreme expression of the bilaterally symmetric pedunculated tubercles at torus occipitalis (TOT) in the female from Saipan, aged 40–44 years, mentioned above (Hanson, 1995). In this particular case, the tubercles at the occipital torus site measure 11 $\times$ 14 mm and extend 7 mm from the outer table. The retromastoid processes are also bilaterally symmetric in size (score = 3; cf. Heathcote et al., 1995) and position. This is the only known female with fairly extreme expression of these traits and it is considered one of the more exceptional examples of TOT in the Marianas.

This same individual also displayed evidence of osteoarthritis in the thoracolumbar spine, the sacroiliac, the hip, and the knees. Furthermore, both calcanei displayed large plantar spurs extending from the medial process of the calcaneal tuberosity and there was marked exostotic development on the tuberosity at the Achilles tendon attachment site. Given the degenerative changes to the hip and knee regions of this particular

Fig. 10. Back transport using tumpline (from Oliver, 1989).

individual, the lack of significant osteoarthritic involvement of the shoulder, elbow, wrist, and hand was conspicuous by its absence.

The general robusticity and evidence for significant biomechanical strain in different regions of this skeleton suggest unusually high levels of physical activity primarily involving the lower back and legs. The development of discrete tubercles along the occipital torus still remains a puzzle and has not been described in any of the known clinical literature. Nor is there any mention of the occipital tubercle development in the current literature dealing with markers of occupational stress (K.A.R. Kennedy, personal communication). The possibility that their formation is due in part to an underlying collagen defect is under investigation (Heathcote et al., 1995). Their bilateral symmetry clearly argues for muscles or muscle groups operating in tandem. It has been suggested (Hanson, 1995) that discrete tubercle development in these islanders may be due to dynamic loading through repetitive or habitual extension/flexion combined with external loading of the head and neck. Transport of heavy loads using a tumpline (Fig. 10), for instance, combines flexion and extension of the head and neck with excessive loading of the cervical spine and significant involvement of the lumbar spine in trunk stabilization during horizontal transport. The lack of significant change in the cervical spine of the female skeleton from Saipan would seem to argue against this hypothesis unless the load was distributed to somehow ameliorate the effects on the cervical vertebrae.

Furthermore, there is very little ethnohistoric information to support the use of tumplines in the Marianas. In fact, tumpline use in Oceania is sporadic and ethnographic evidence for their use is largely restricted to Melanesia (Oliver, 1989; MacKenzie, 1991). Heathcote et al. (1995) have expanded upon this hypothesis in some detail and offer several alternative explanations.

RESEARCH TRAJECTORIES

Despite recent progress, bioarchaeological research in the Marianas is still in its descriptive phase and is largely hampered by the lack of regional synthesis and a coherent set of unifying hypotheses for directing our research efforts. With the papers presented in this symposium we've taken an important first step in pulling our work from the appendices and buried chapters of a rapidly expanding grey literature for the Marianas and focusing some attention on specific gaps in our knowledge as well as broadening the scope of our individual research endeavors in this region.

Those of us who have worked in this region of the Pacific are aware of a number of critically important research areas which have been barely touched upon in this paper because our knowledge pertaining to these areas is still fairly limited. These research domains include but are not limited to 1) the antiquity of amyotropic lateral sclerosis and parkinsonism dementia (ALS/PD) in the Marianas and whether there is paleodemographic evidence and primary and/or secondary skeletal indicators of this late onset neurodegenerative disease complex. Until recently ALS/PD was endemic to the Marianas and its etiology has been convincingly argued to be environmental in origin; 2) the antiquity and epidemiological significance of leprosy in the Marianas; and 3) evaluating changes in epidemiological patterning of endemic yaws with the introduction of epidemic syphilis to the islands with the arrival of the Spanish.

Finally, several of us have begun work on samples which span the Latte and Early Historic so that were in a much better position to begin evaluating the biological impact of European contact on these island populations.

In order to make continued progress towards furthering our understanding of human biological adaptation in the Marianas, it is necessary to begin a step-by-step process of coordinating and consolidating our research efforts. This becomes critically important as we begin to move towards a period of "quick turn-around analysis and reburial," particularly in the case of Guam. It is necessary to begin standardizing data collection and reporting procedures using a model similar to that developed by the Human Skeletal Database Committee of the Paleopathology Association and recently published as the Standards manual (Buikstra and Ubelaker, 1994).

We're rapidly entering an era in which information technology is critically important to the way we do scientific research, particularly for collaborative groups of individuals as widely scattered as those of us conducting research in Marianas bioarchaeology. The National Research Council published a report in 1993 endorsing the establishment of national and international research "collaboratories" in which several testbed collaboratories in oceanography, space science, and high energy physics were proposed. Following this initiative, we've begun development of a scaled-down version of a collaboratory envisioned by the NRC—the Virtuary Research Collaboratory for Marianas Prehistory and Bioarchaeology (VRCMPB) (http://www.forsyth.org/marianas). Utilizing newly emerging database technologies being developed for the World-Wide Web, this virtual collaboratory will incorporate a front-end to a shared relational database which will enable investigators not only to contribute their own data, but from which they can retrieve selected data arrays for their own research. In addition, this collaboratory will soon serve as a repository for searchable full-text reports from the "gray" literature for the region. Finally, several interactive discussion areas will be established in the collaboratory to enable investigators to work together on ongoing projects.

It is hoped that this collaboratory will serve as a model for similar initiatives and enable interested investigators throughout the world to participate in our research endeavors. It is hoped that the VRCMPB will eventually serve as a single node in a distributed network of research nodes devoted to Oceanic prehistory and bioarchaeology. The speed and level of information sharing made possible by many of the emerging enabling technologies will contribute substantially to our understanding of human adaptation in the Pacific in the coming century.

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